A Smarter California Transmission Grid: Synchrophasors for enhanced protection

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California Energy Commission
Transmission Research Program Discussion Group
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Center
for Power and Energy
Engineering

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Two Research Projects

- Advanced Protection System Using Wide Area Measurement
  - Nov. 2006 to Dec. 2009

- Adaptive Relaying Technology Developing Measurements
  - Jan. 2009 – Dec. 2011

  Technical Advisory Group
  - PG&E
  - SCE
  - QUANTA Technology and Others

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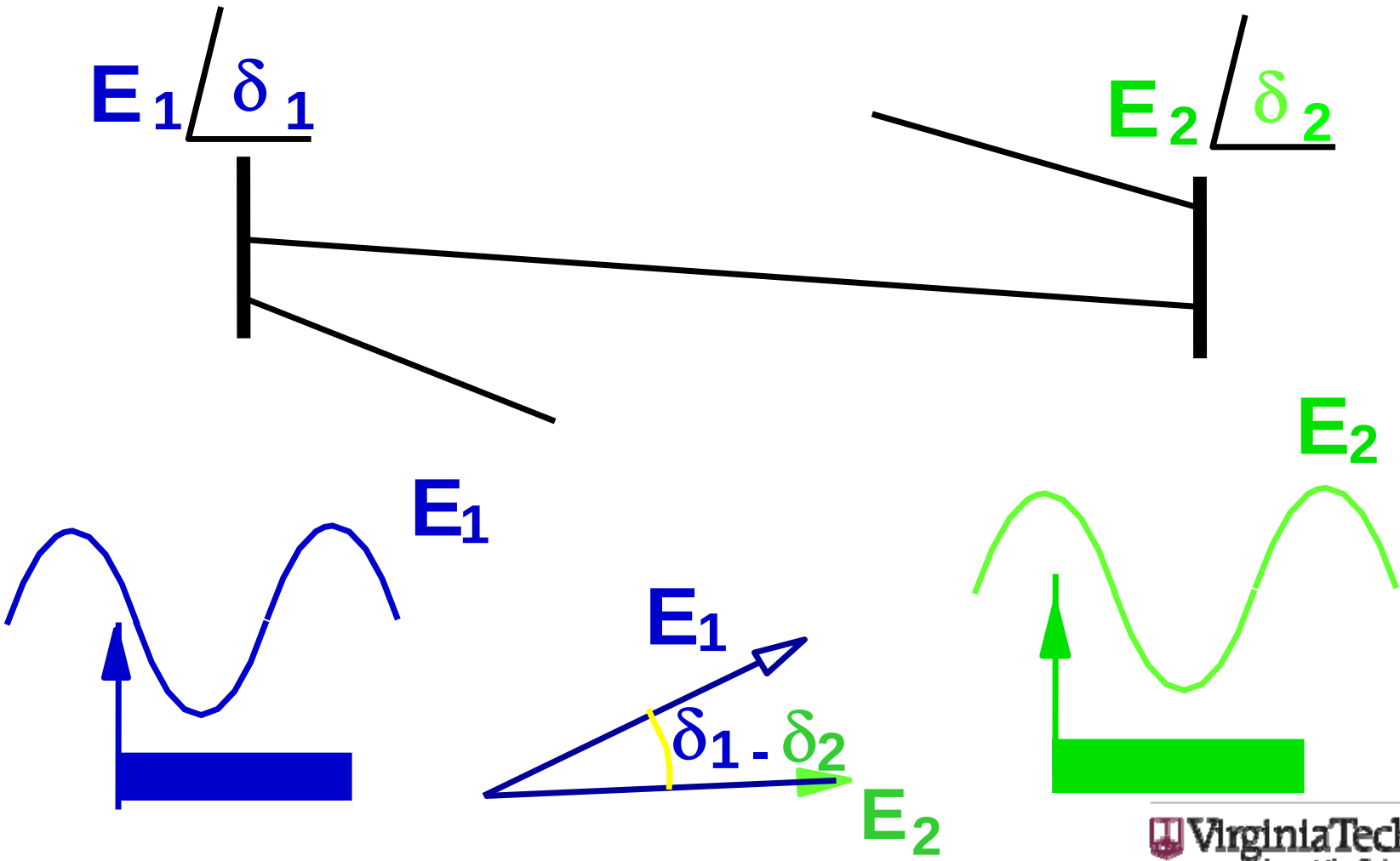
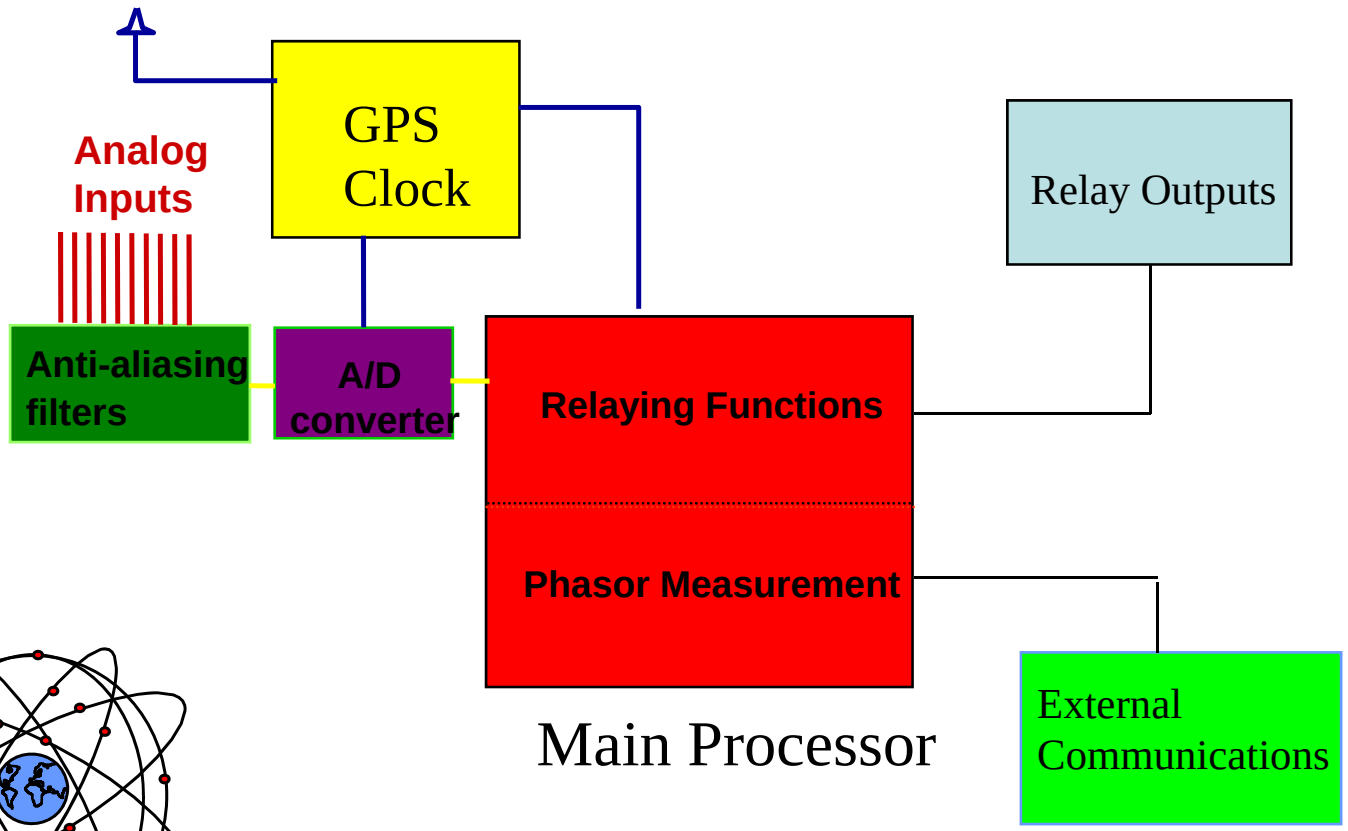
Objective

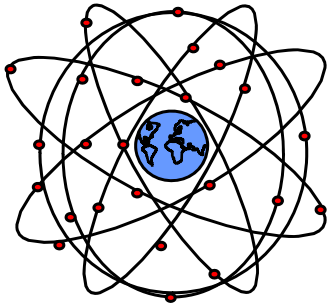
- Develop techniques to enable the use of real-time wide area measurement data for the improved supervision of the protection system in order to make it more adaptable to prevailing system conditions.

Wide Area Measurement



Current Technology





Project 2: Adaptive Relaying Technology Developing Measurements

Task 1: Develop Techniques to Supervise Over-Reaching Zones (zone 2)

Task 2: Develop an Adaptive loss-of-field Algorithm

Task 3: Develop Intelligent Load Shedding Techniques

Task 4: Develop PMUs application for damping of low frequency oscillations

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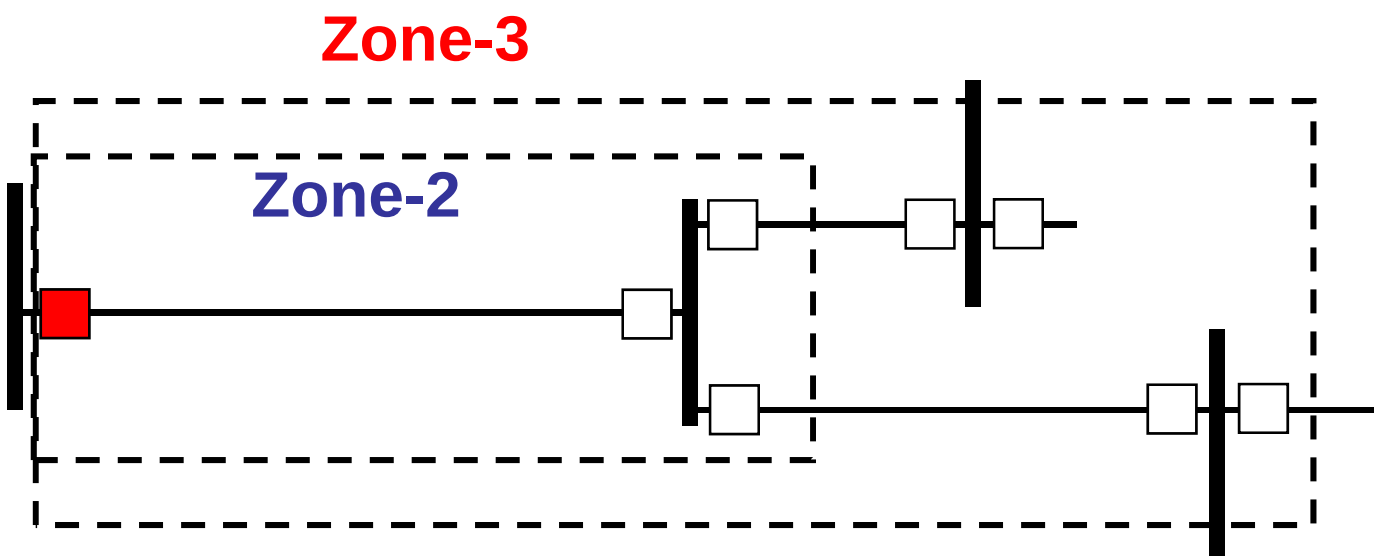
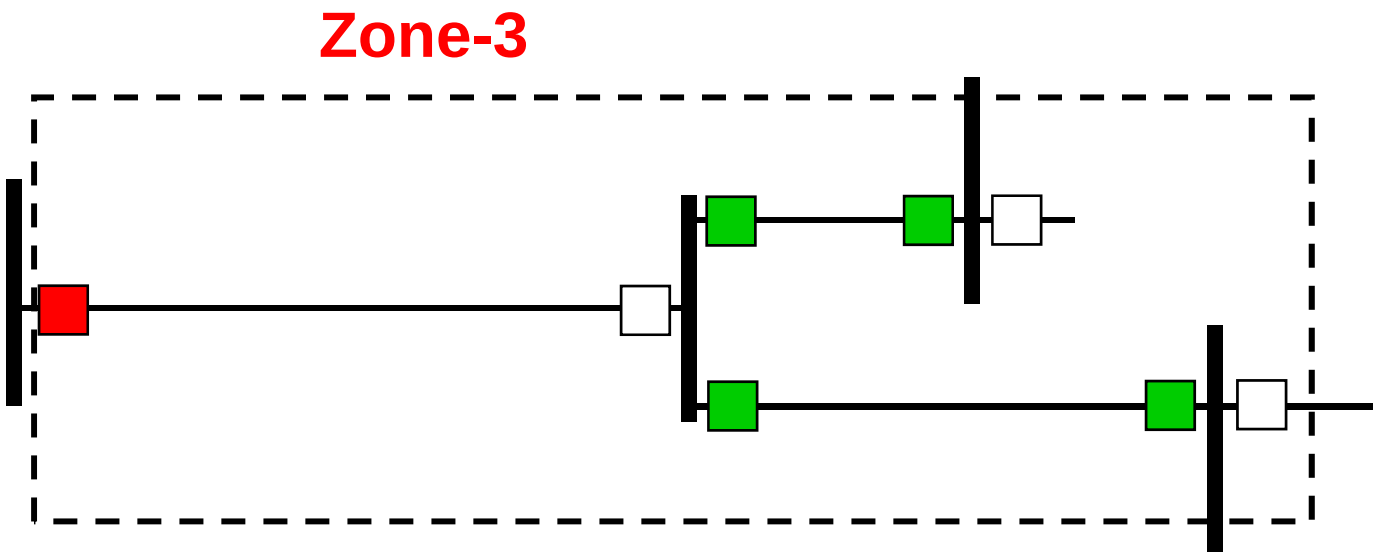
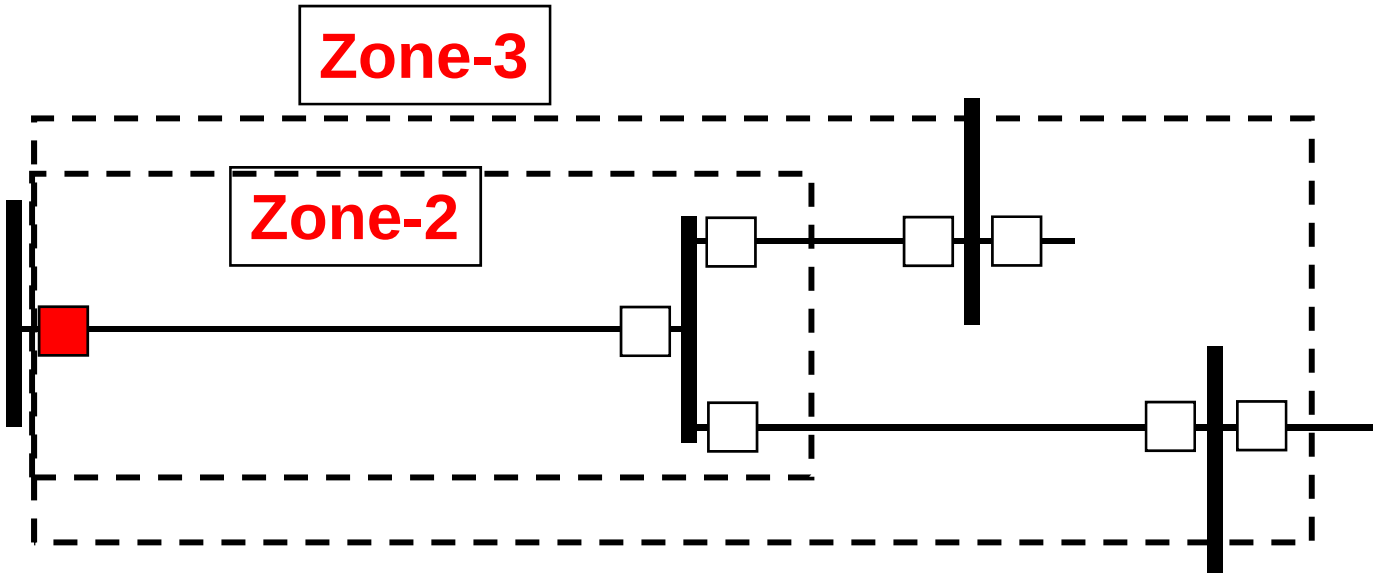
Task 1: Develop Techniques to supervise over-reaching zones

Problem: Over-reaching zones (2 and 3) of distance relays are susceptible to false trips due to load encroachment during stressed system conditions.





If zone-3 at ■ picks up, PMUs at one of ■ must indicate zone-1 fault for trip at ■ to be permitted.

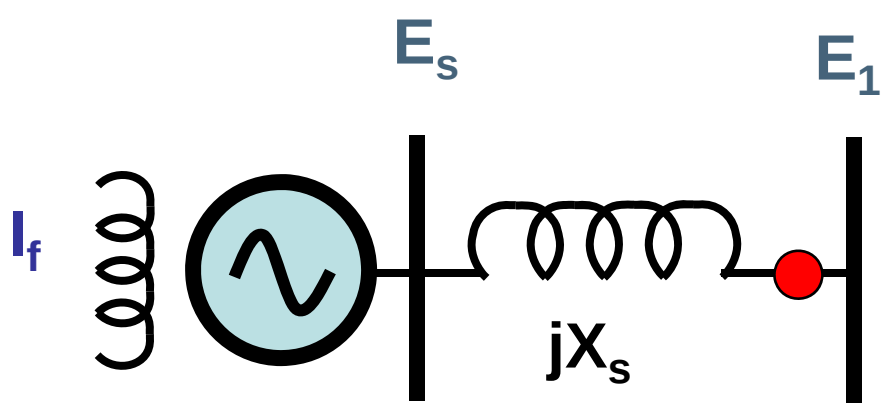


- Identify buses where PMU checks will be required for supervision

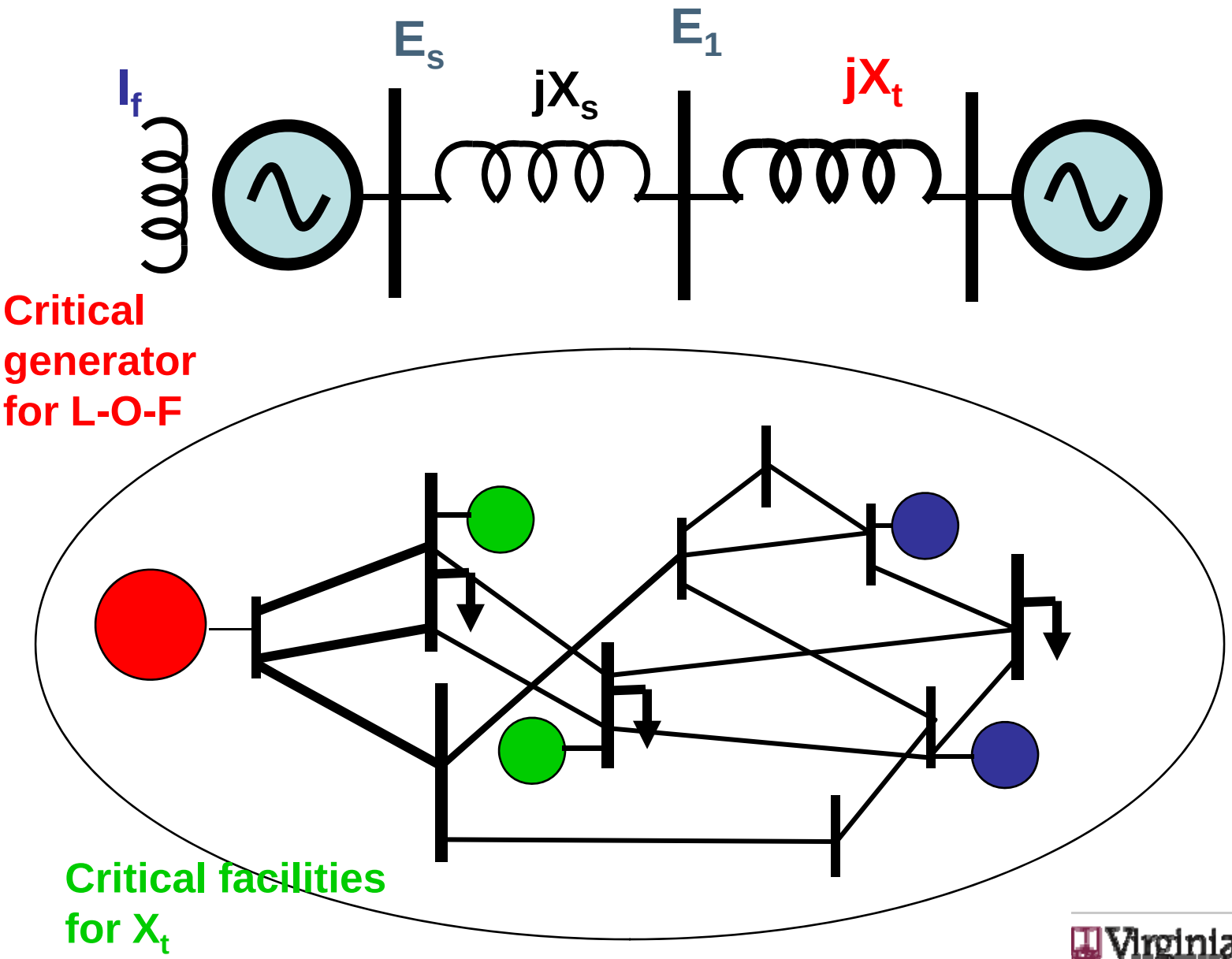
- Implement supervision logic in simulation with latency variations due to communications

Task 2: Adaptive loss-of-field

Problem: Settings of loss-of-field relays depend upon network conditions. As the power system becomes weaker due to cascading failures the loss-of-field relays are no longer appropriate for the prevailing power system state.



L-O-F relay



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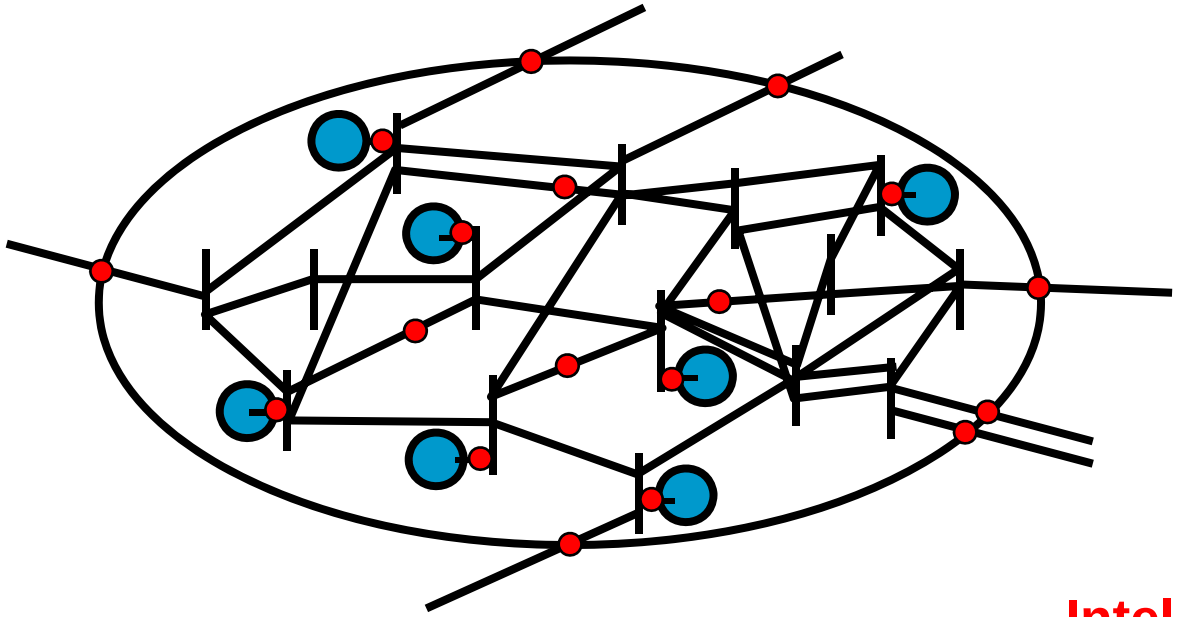
Task 3: Intelligent load shedding

Problem:

Under-frequency load shedding works well after islands with mismatched load and generation are formed.

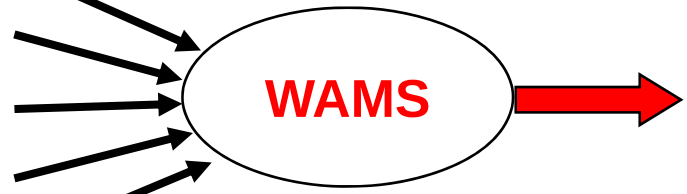
It would be desirable to generate real time signals indicating a growing imbalance in load and generation in a region before islands are formed.

Simulations on Test System



Intelligent
Load shedding
Signals

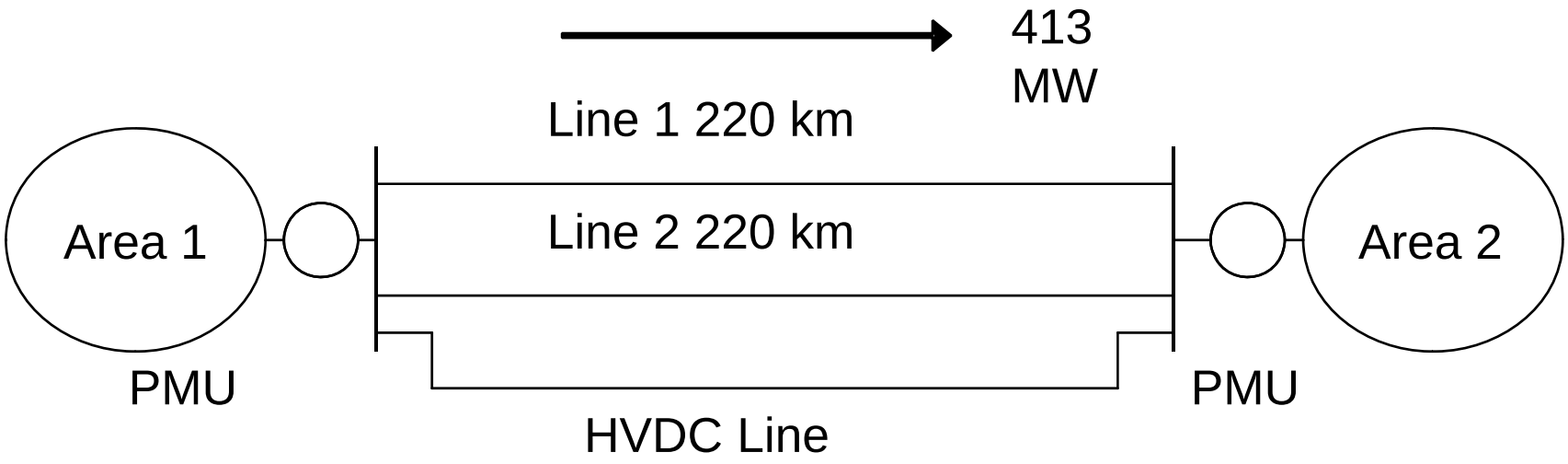
Dynamic ACE
Dynamic Reactive ACE
Generator capability margins
Critical line loading margins
Critical bus voltages



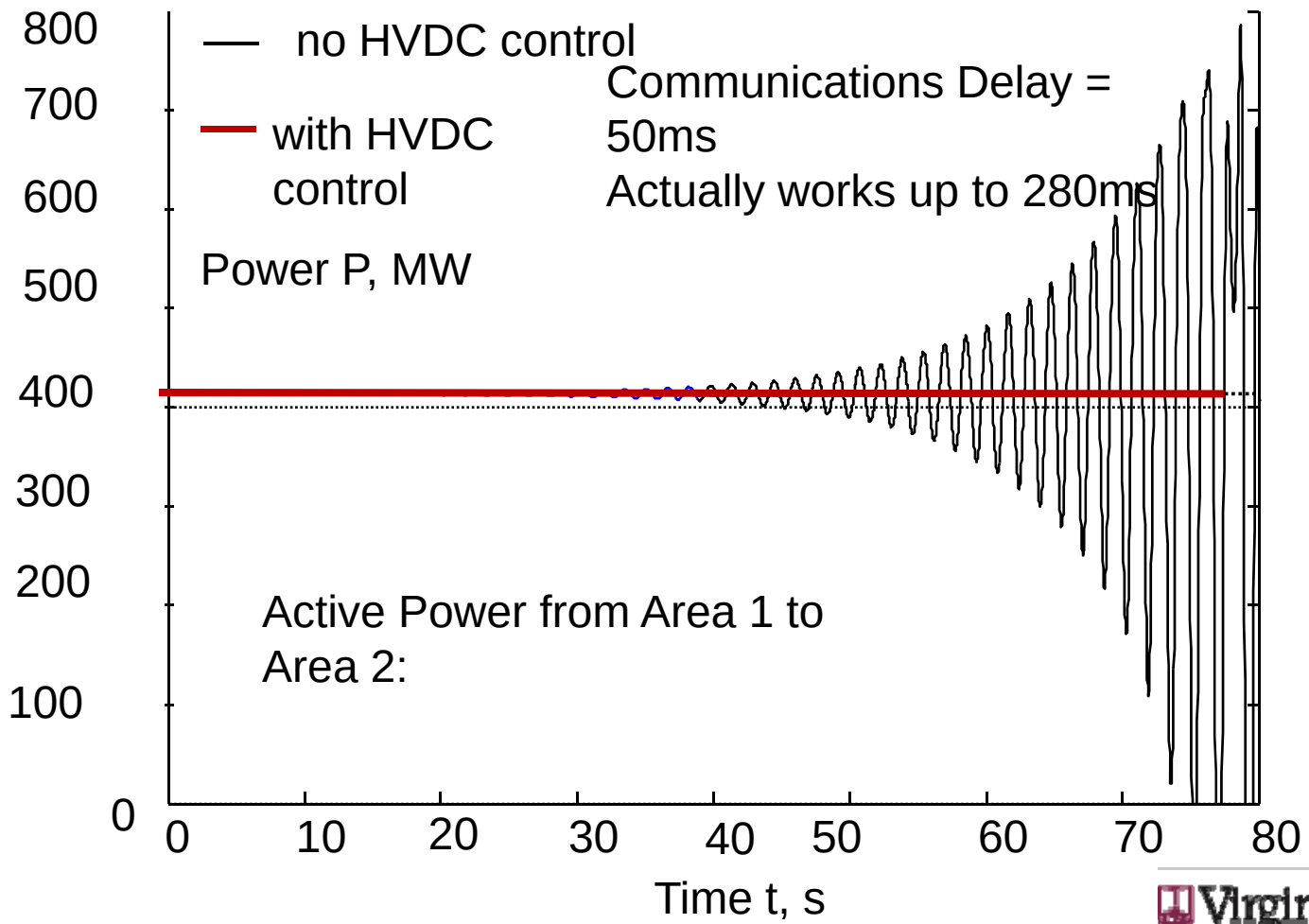
Damping oscillations with few measurements and with model uncertainty

- Structures
  - Large flexible space structures. An astronaut running on a treadmill provides a periodic excitation. Structure has very little damping
  - Tall buildings in earthquakes (Building 101 Taipei)

Example with a DC line



0.64 Hz mode between two areas


no HVDC control
with HVDC control
Communications Delay = 50ms
Actually works up to 280ms
Power P, MW
Active Power from Area 1 to Area 2:
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
Time t, s

Model Development

Requires proper low frequency modes exist between equivalents and California model

The proposed methodology will be exhaustively tested on the test system for all contingencies and loading levels with all selected locations and DC lines.

Methodology Development for DC lines will be extended to FACT devices and generator excitation systems

Project 1: Advanced Protection System Using Wide Area Measurement

I. Alarming on potential load encroachment,

II. A more intelligent out-of-step relaying on critical tie-lines

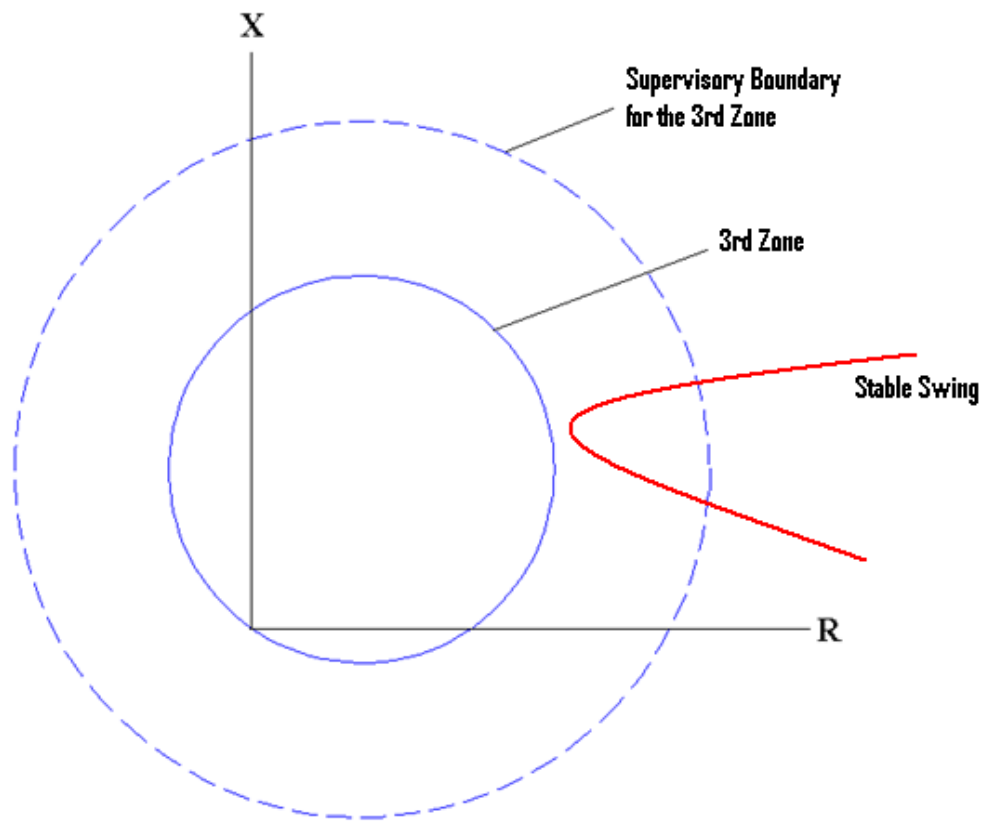
III. Adaptive adjustment of dependability and security

I. Alarms for Encroachment of Relay Trip Characteristics

- Look at Following Relays:
  - Distance
  - Loss of Excitation
  - Out-of-Step
- Concentrated on Path 15 and Path 26
- Alarm system
  - Provides information and warning to engineers
  - Essentially a time-saving tool

Distance and Loss of Excitation Cases

The supervisory boundary is a concentric circle 50% larger than the largest zone of the relay.



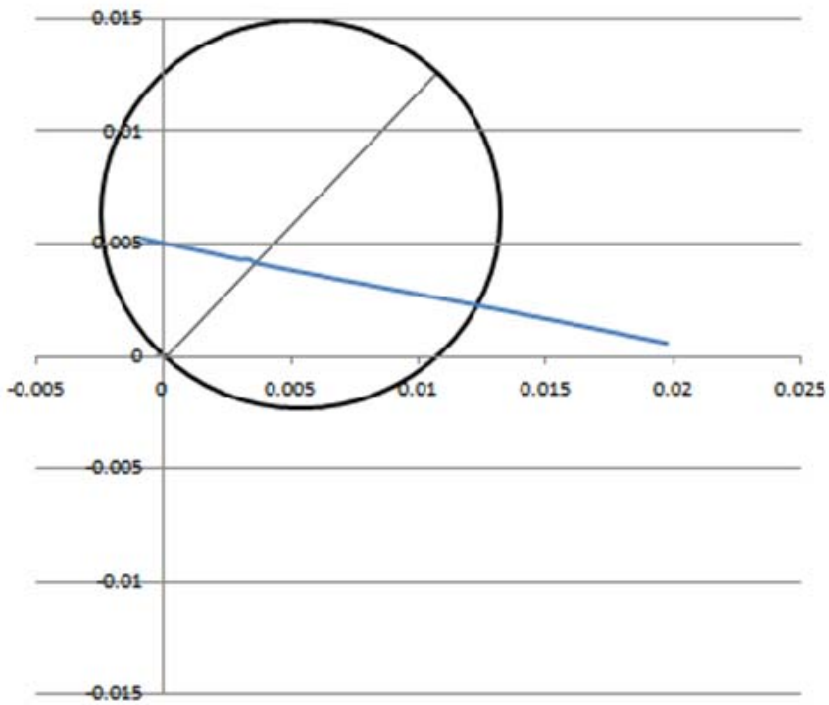
Distance relays most susceptible to encroachment due to power swings or increasing power flow:

Line Name	Dist. From Z2/ Radius of Z2
Midway-Vincent ck 3 500kV	1.07
Midway-Vincent ck 2 500kV	1.12
Midway-Vincent ck 1 500kV	1.12
Los Banos-Midway ck2 500kV	3.59
Diablo-Midway ck 3 500kV	4.05
Diablo-Midway ck 2 500kV	4.36
Diablo-Gates 500kV	4.93
Vaca Dixon-Cottonwood 230kV	4.94

Phasor measurement units at
Midway 500kV, Los Banos 500kV, Diablo 500kV, and Vaca-Dixon 230kV will be needed to monitor these lines.

Out-of-Step Encroachment

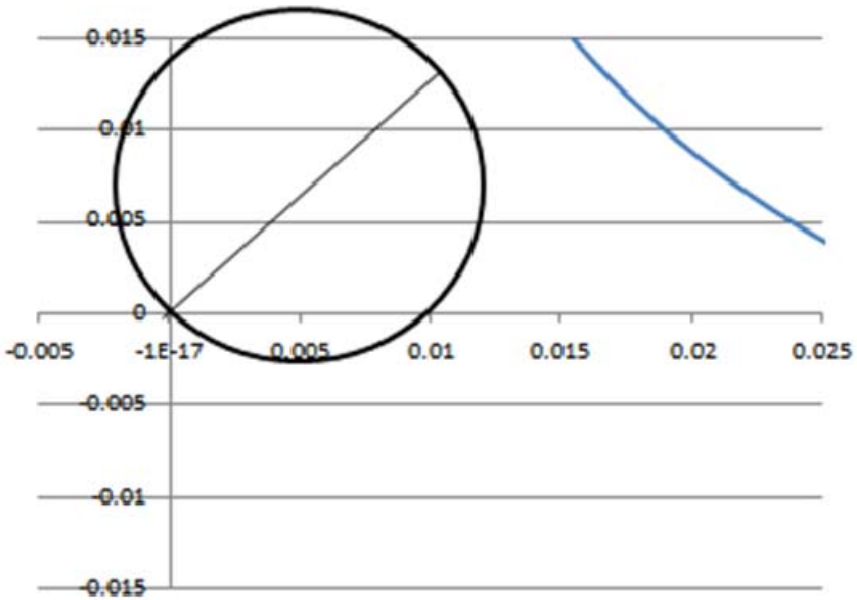
Identify conditions and contingencies that significantly change the location of the swing center (trajectory) of the apparent impedance of an unstable swing at the location of the relay.



OoS Swing at Captain Jack – Olinda

Same contingency with the Maxwell-Tracy line out-of-service.

New trajectory will not trip a typical out-of-step relay at Captain Jack for an unstable power swing.



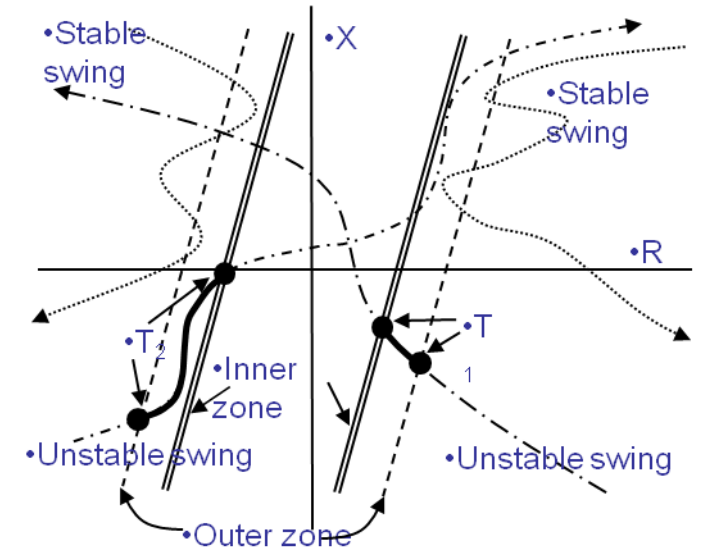
OOS Swing at Captain Jack – Olinda with Maxwell - Tracy out-of-service

II A more intelligent out-of-step relaying on critical tie-lines

Traditional Out-of-Step Protection

Impedance relays and timers are used to detect and protect against unstable oscillations.

Settings are determined from results of a large number of simulations under different conditions.



•***Figure 2:*** *Traditional out-of-step relay parameters using reactance type relays and timers.*

Approach for a “Multi-machine” Swings

- Determine coherent groups of machines.
- Place PMUs on buses electrically close to the coherent groups, so swings can be observed.
- Infer rotor angles from measured voltage angles.
- Swing Protection Algorithm
  - Time series extrapolation

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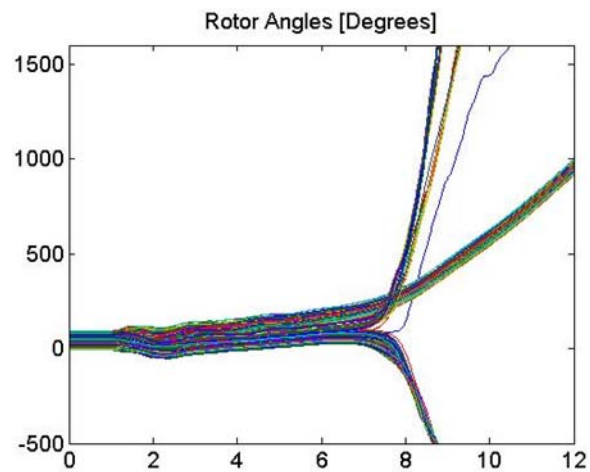
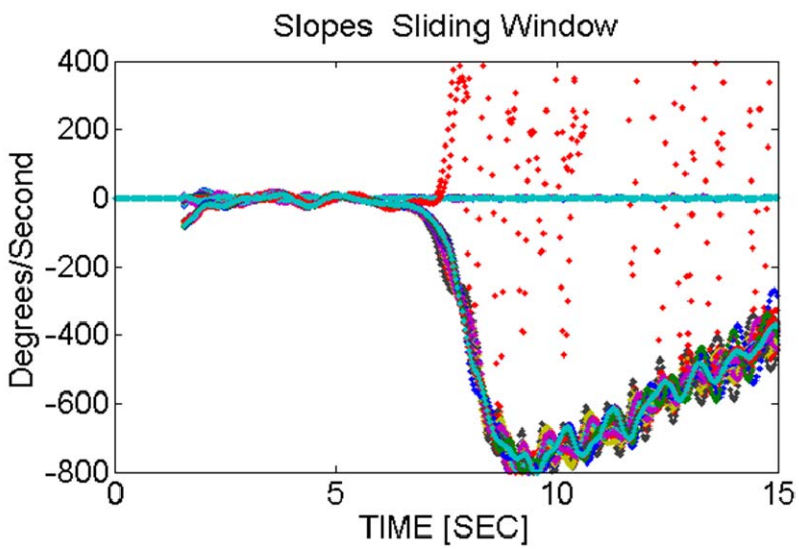
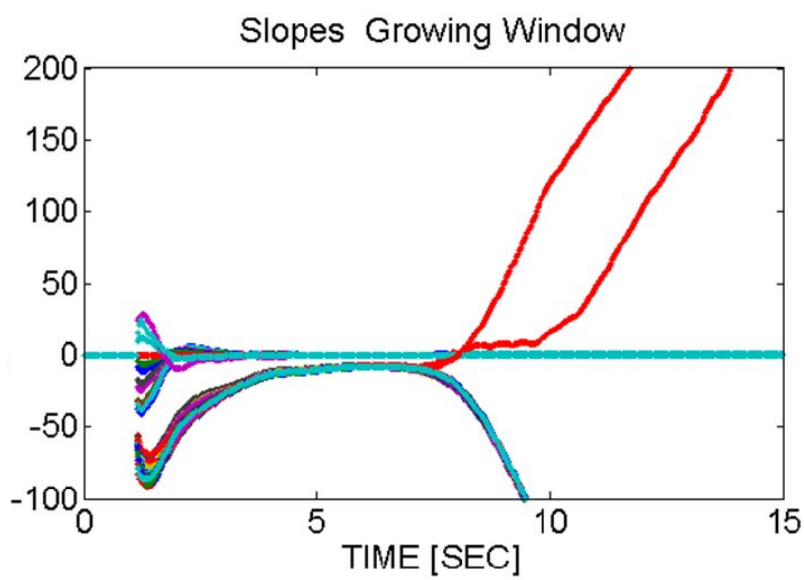
Angle Slope was used to Determine Coherent Groups

Midway-Vincent Heavy Winter
1 Fault & 2 Hidden Failures



Rotor Angles





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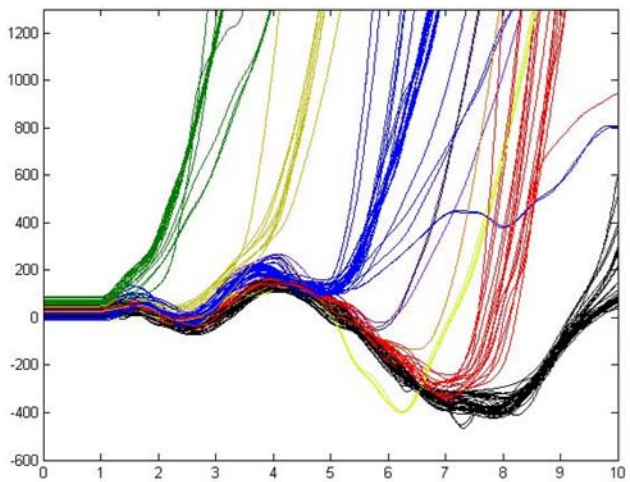
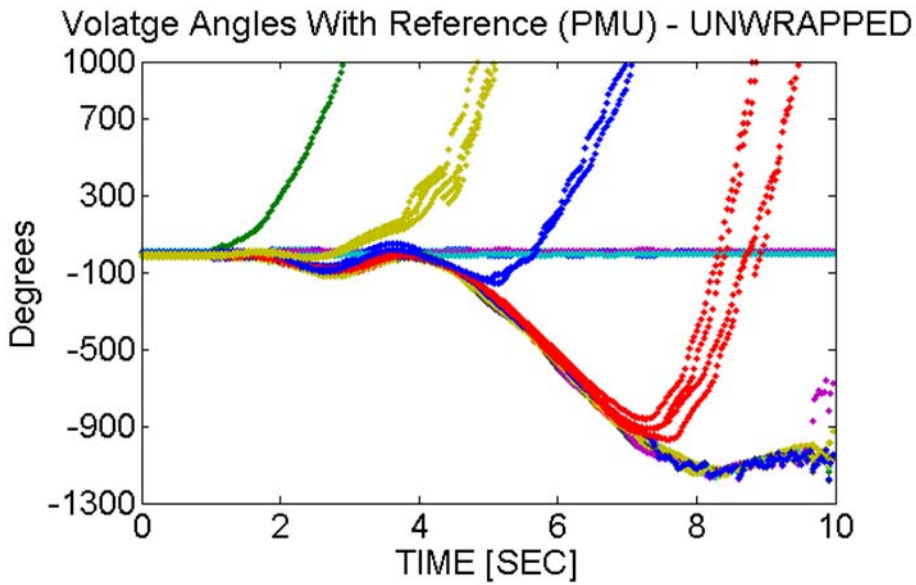
PMU placement based on coherent groups

1) LOSBANOS 500 kV
2) DIABLO 500 kV
3) KRAMER 230 kV
4) IMPERIAL VALLEY 230 kV
5) MAGUNDEN 230 kV
6) SAN ONOFRE 230 kV
7) MOUNTAIN VIEW 230 kV
8) HAYNES 230 kV
9) MORROBAY 230 kV
10) ELSTEAMP 92 kV
11) MIDWAY X 92 kV
12) OLIVE_69 69 kV
13) REDON7 G 20 kV
14) ALAMT3 G 18 kV
15) ELSEG3 G 18 kV
16) CASTAI2G 18 kV
17) HUNT1 G 13.8 kV

PMU angles were computed using simulated sampling



Rotor Angles



PMU Angles

Lugo- Heavy Winter
Breaker Failure Case

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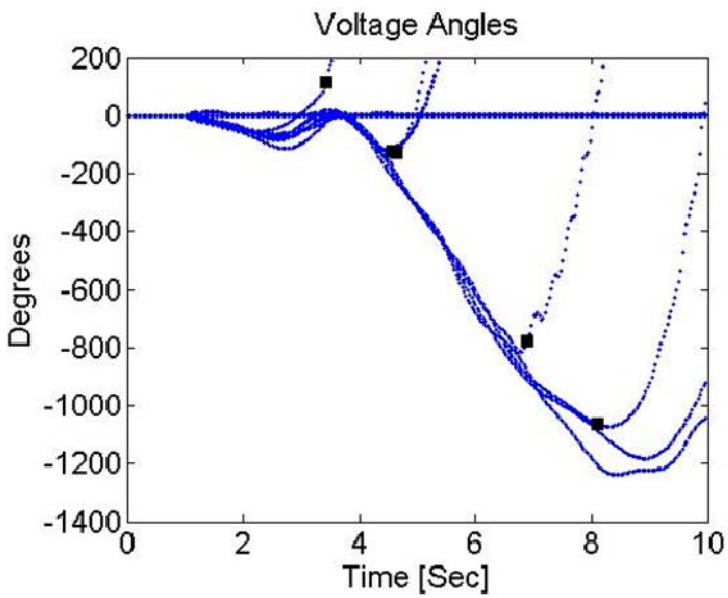
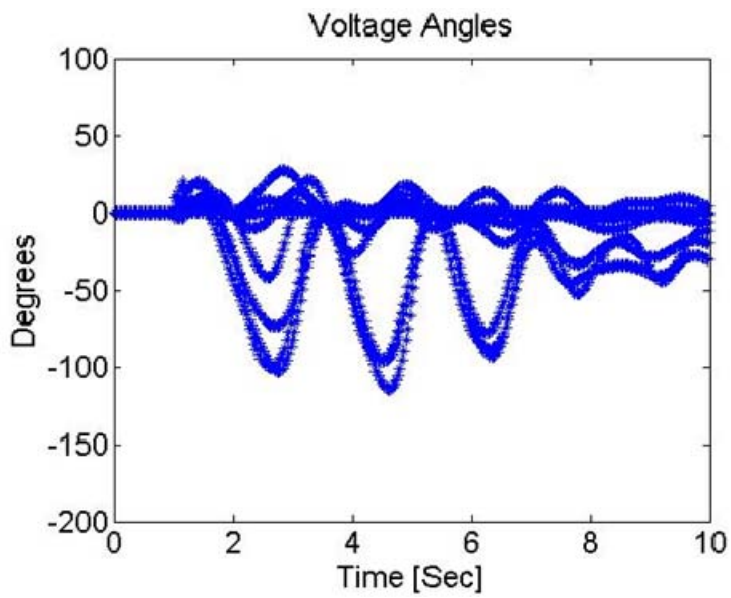
Predicting Algorithm:

After two consecutive predicted angle differences of 150 degrees between a given voltage angle and the COA an unstable swing is declared



Unstable Case



Stable Case

III. Adaptive Adjustment of Dependability and Security

- Methodology Voting Scheme:
  - Stressed → Security = Vote
  - Safe → Dependability = Don't Vote
- High Accuracy Decision Tree.
- We are **NOT** changing relay settings neither during, before or after a fault.

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Methodology:

- Where?

Static Index

Dynamic Index

Critical Location

- How?
- PMUs?

System State

Fault and HFs

Check Solution

Vote Decision

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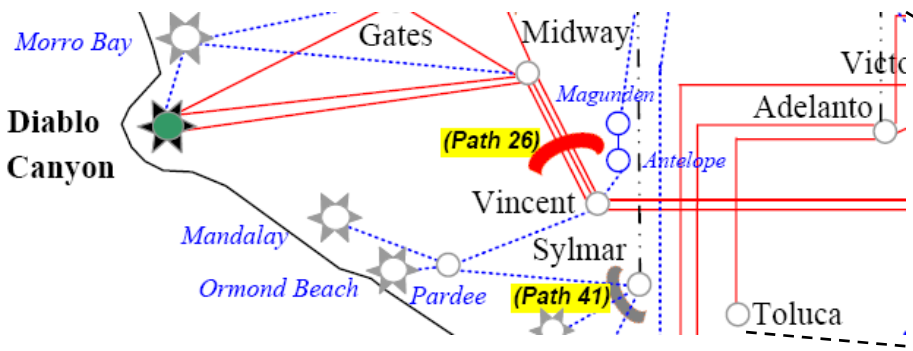
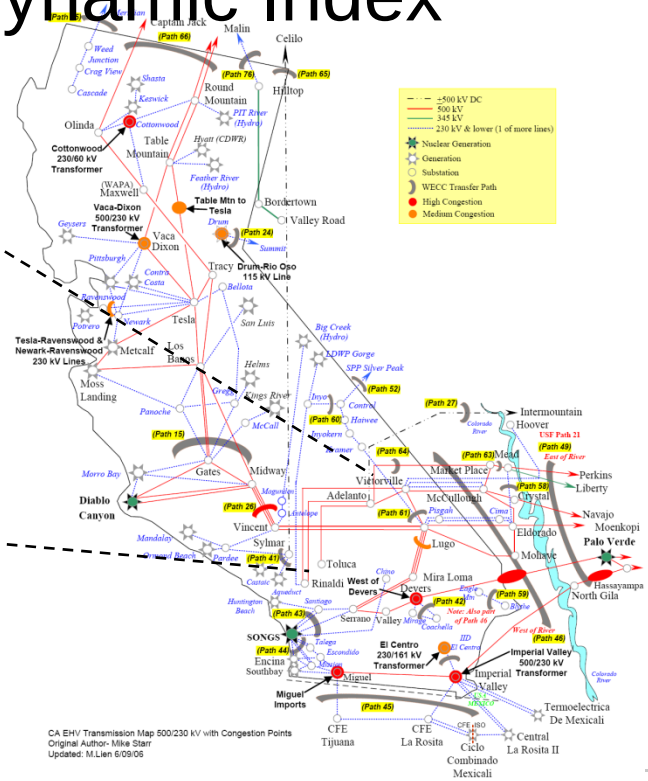
Critical Location:

- Midway - Vincent
- One Fault, two Hidden Failures.
- Determined by Static and Dynamic Index



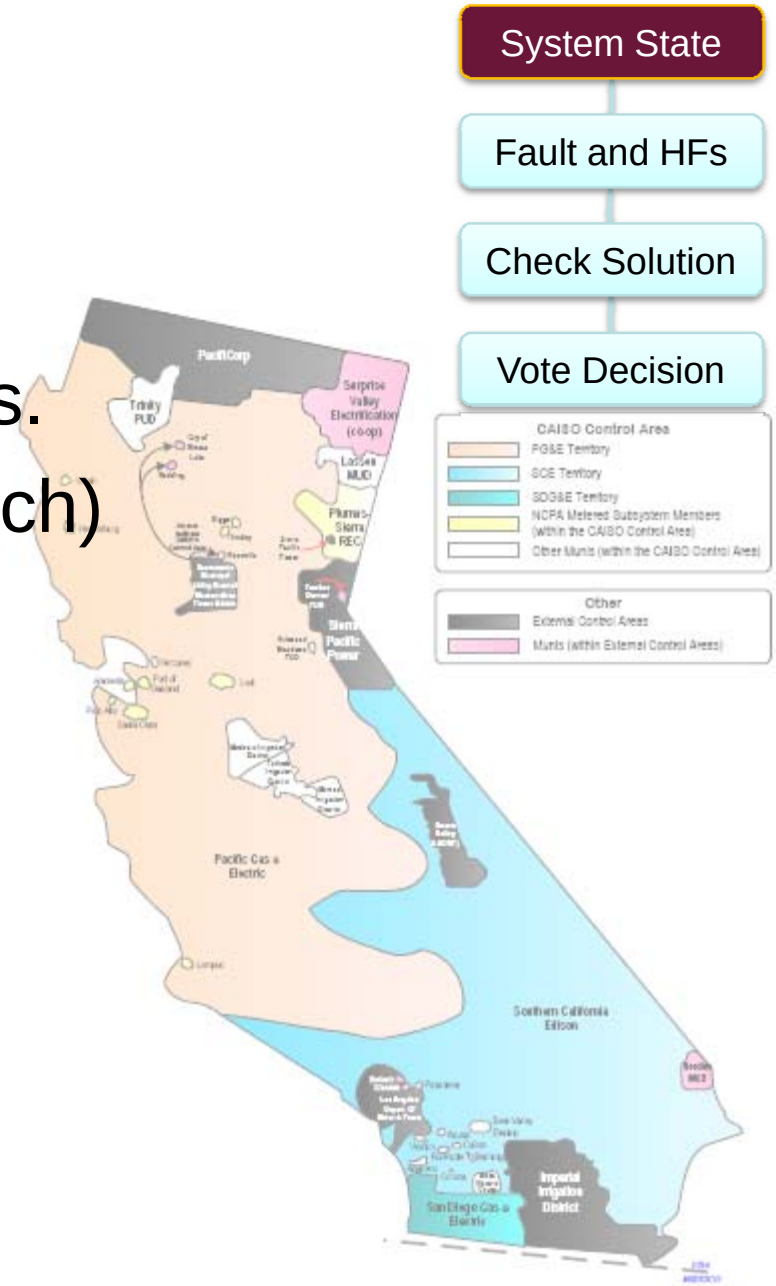


Training Cases

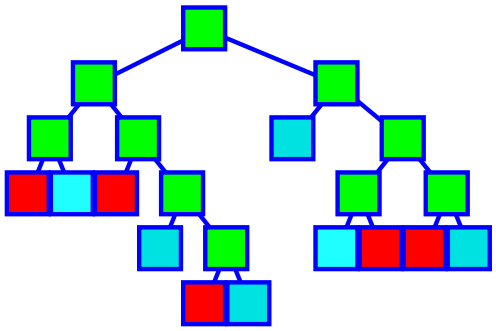
- Varying System Conditions.
- Load Scaling (no re-dispatch)

NUMBER	NAME
30	PG&E
24	SOCALIF
26	LAWGP
22	SANDIEGO

- Total # Cases = 4150

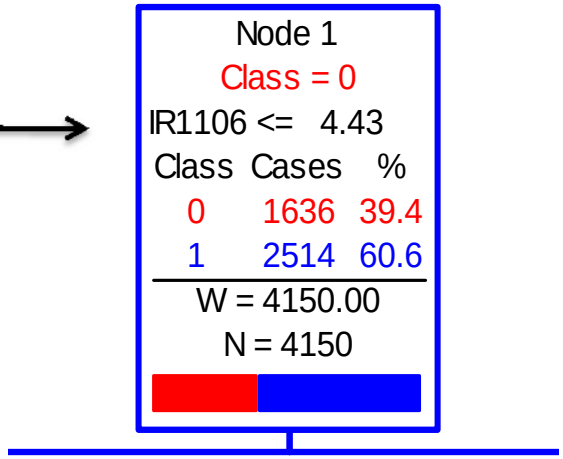


Data Mining: CART

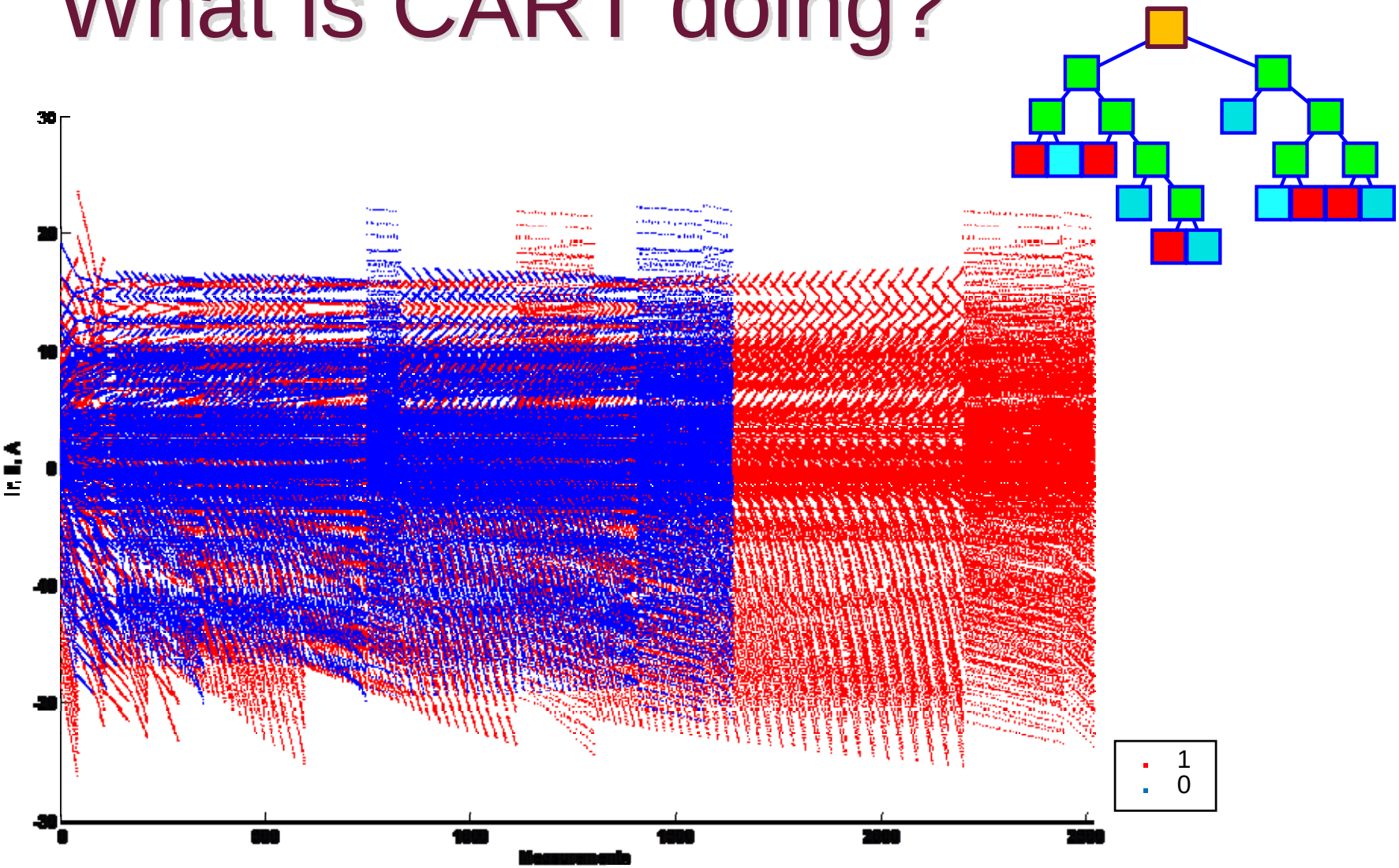


- Proposed Decision Tree:
  - Nodes = 11.
  - ROC: probability of correctly distinguishing 1 and 0. (Receiver Operating Characteristics).
  - ROC = 0.99.
- Splitters ⟶ PMU placement

IR1106: Real Current Tesla – Los Banos ⟶

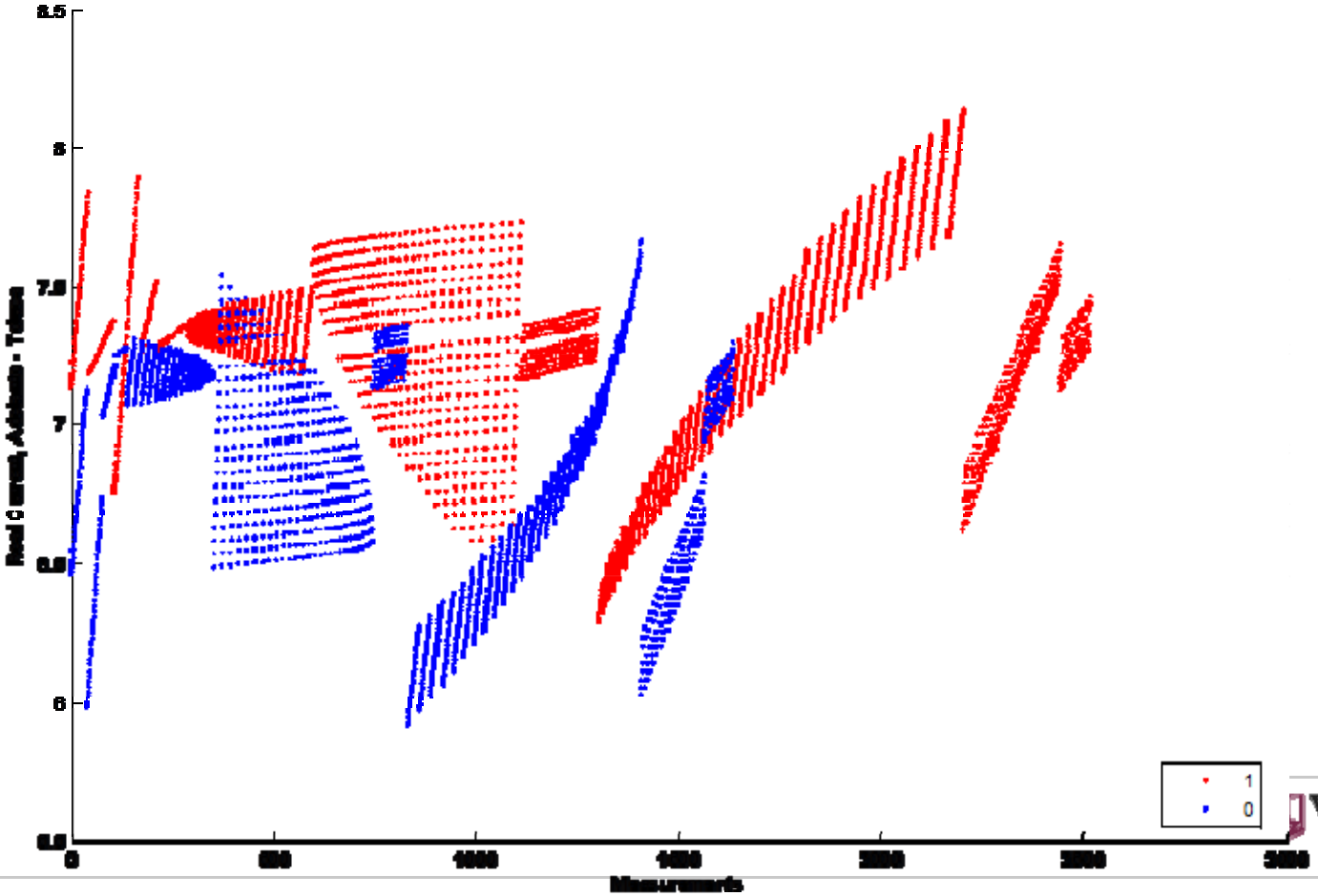


What is CART doing?



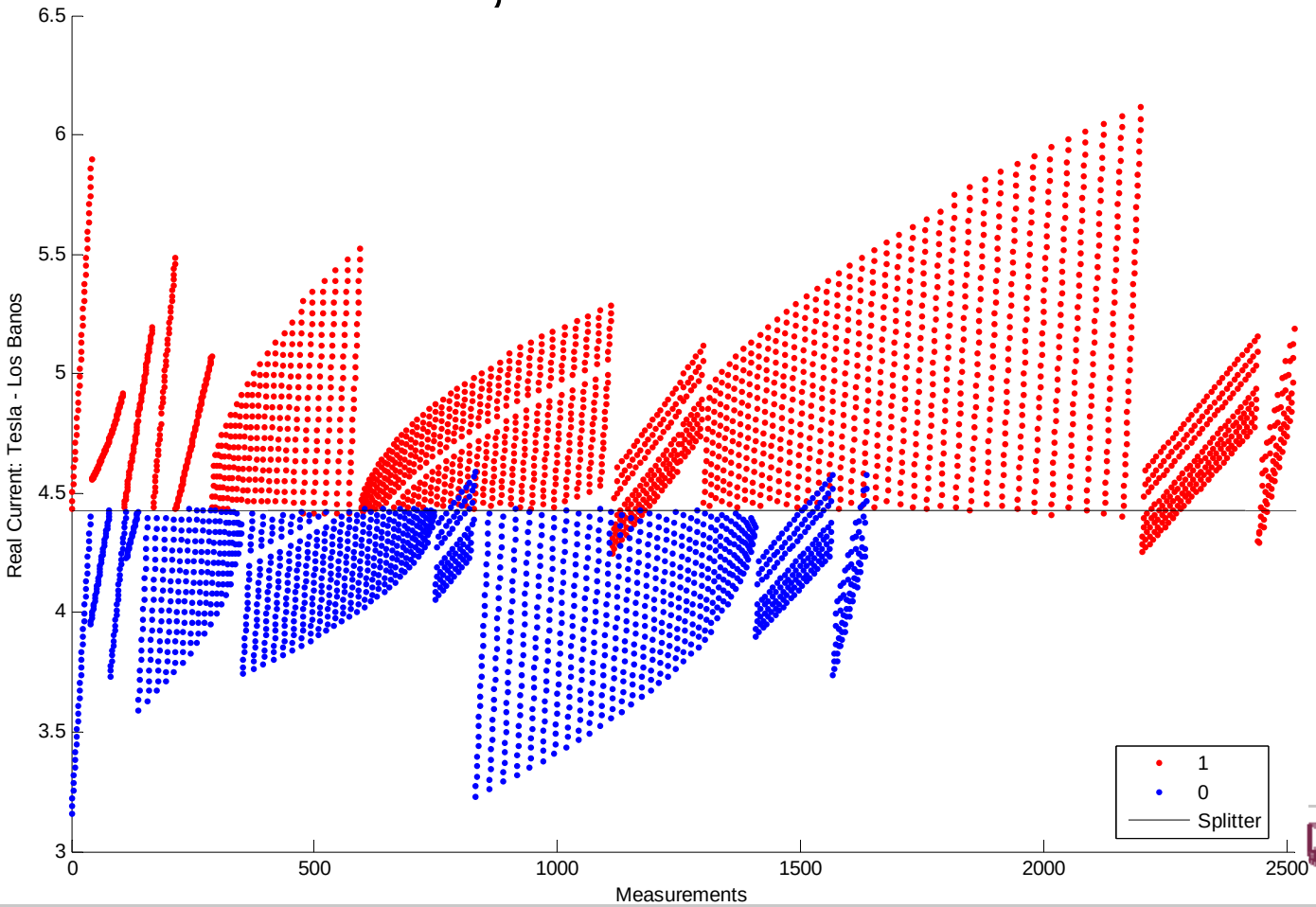
CART determines predictors

- Bad Predictor: Ir, Adelanto - Toluca



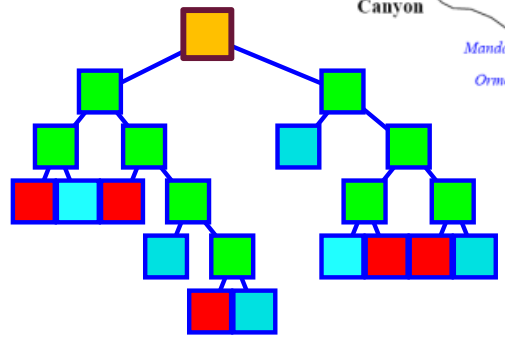
Good Predictor

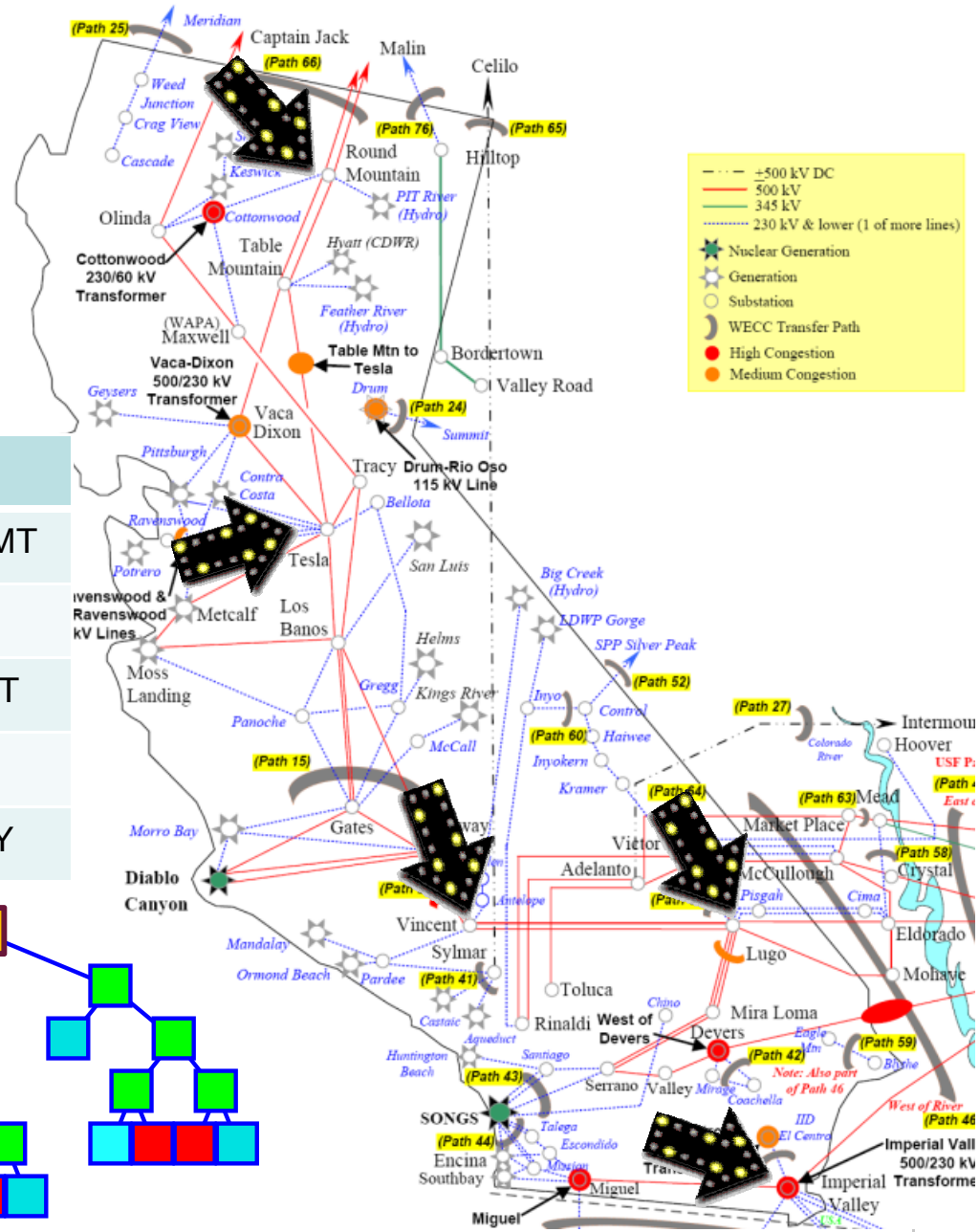
- Predictor: Ir, Tesla – Los Banos



PMU Placement:

Line Current			PMU
TESLA	LOSBANOS		ROUND MT
LOSBANOS	MIDWAY		TESLA
N.GILA	IMPRLVLY		VINCENT
TRACY	TESLA		LUGO
LUGO	VINCENT		IMPLVLY
METCALF	MOSSLAND		
LUGO	MOHAVE		
MALIN	ROUND MT		





Recent DOE award will allow us to test two of the developed techniques with real measurements

Adaptive Adjustment of Dependability and Security

Encroachment Alarms

Questions?